

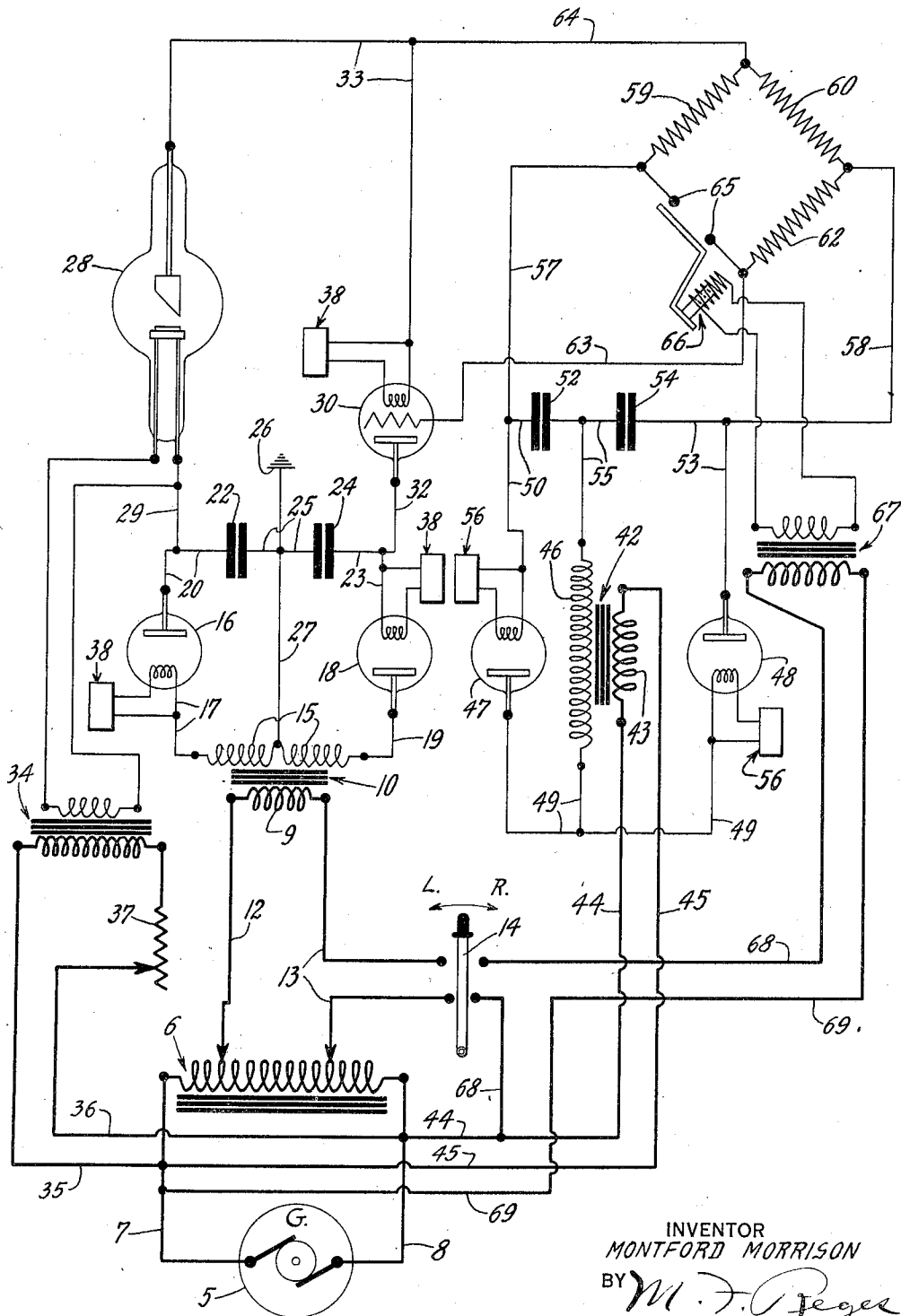
Dec. 7, 1937.

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2,101,152

X-RAY APPARATUS

Filed Dec. 24, 1931



UNITED STATES PATENT OFFICE

2,101,152

X-RAY APPARATUS

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Application December 24, 1931, Serial No. 582,933

2 Claims. (Cl. 250—34)

My invention relates to X-ray apparatus and has particular relation to an apparatus for taking short exposure X-ray photographs.

It is well recognized that in order to obtain successful radiographic exposures of short duration the X-ray tube must be subject to heavy currents at high potential. High tension transformers capable of energizing the X-ray tube with the requisite currents and potential of sufficient magnitude would of necessity be so large that they are commercially limited. In view of these limitations on transformers, condensers are usually employed having a capacity sufficient to permit the storing therein of all the energy required for energization of the X-ray tube.

In the prior art systems employing condenser discharges for the taking of so-called instantaneous or short exposure radiographic exposures have been utilized. Such systems are, however, defective in practical applications due to the manner in which discharge of the condenser takes place. In these prior systems the condenser is charged to a predetermined amount which, when reached, is of sufficient value to cause breakdown of a spark gap in series with the X-ray tube and condenser thus causing discharge of the latter through the X-ray tube with a resulting radiographic exposure.

Systems of this type are therefore limited by the maximum capacity of the condenser before breakdown of the series connected gap and no provision for limiting the X-ray tube energization can be made other than the limits fixed by the condenser itself. The resistance of the spark gap will vary with climatic conditions which changes the breakdown characteristic thereof.

Consequently the total amount of energy stored in the condenser will vary in accordance with the variation in resistance of the spark-gap. When the maximum energy is stored in the condenser the well known "brush discharge" or leakage across the gap will occur before the complete breakdown of the gap. The leakage or "brush discharge" will naturally be transmitted to the X-ray tube producing X-rays before the full energy is impressed thereupon with detrimental effect upon the radiographic picture. Furthermore, exposures of various time periods cannot be accomplished in a system of this type as there is no provision for regulating either the energy passing through the X-ray tube or the period of time required to discharge the condenser.

It has also been proposed to cause the discharge of a condenser device for taking short exposure radiographic pictures by maintaining the

temperature of the cathode of the X-ray tube below saturation, i. e., at a temperature below that necessary to permit electron emission of the cathode and to then suddenly increase this temperature to the saturation value. This is accomplished by short circuiting a resistance in the primary of the low tension cathode-heating transformer enabling the temperature of the cathode to reach saturation with an attendant discharge of the condenser. Such systems are likewise objectionable in that an appreciable lapse of time occurs after short circuiting of the resistance in the primary winding before the cathode reaches maximum temperature. This is due to inherent losses in the cathode heating transformer and the heat inertia of the cathode which is lost from the actual exposure period.

Although this time period is relatively small the discharge of the condenser will start and gradually rise with a rise of cathode heating temperature resulting in a non-uniform flow of energy from the condenser and considerable variation in the intensity of the X-rays emanating from the tube.

A further unsuccessful system for taking X-ray photographs has been proposed wherein an endeavor is made to control the flow of energy through an electron discharge device by means of a magnetic field. It has been found, however, that due to the high potential of the X-ray circuit the magnetic field cannot be made sufficiently high enough to positively prevent the flow of energy through the discharge device and consequently the X-ray tube. Although the magnetic field will divert a portion of the electron flow of the discharge device it will not prevent a portion of the same flowing between the electrodes of the device.

The high potential will accordingly flow and energize the X-ray tube as long as the source of supply is energized. This results in the radiographic film being exposed to X-radiations of a lesser intensity which is merely increased by removal of the effect of the magnetic field. Accordingly as X-rays are emanating from the X-ray tube during the entire period that the source is energized no instantaneous radiographic exposure can result with the system being wholly inoperative for the purpose intended. In this proposed system the source of energy which creates the magnetic field must be completely insulated from the source of high potential energy to prevent spark-over. This insulation requirement tends to further weaken the magnetic field and render the system inoperative.

I have found that by employing a thermionic discharge device, such as that shown in my co-pending application, filed March 5, 1932, Serial No. 596,948, as a switching means in the high tension circuit I can control the same with minute precision. By employing a novel circuit arrangement in which the switching device is connected in series with the X-ray tube and a source of high potential heavy current energy, such as a high capacity condenser, the discharge of the latter can be absolutely prevented until it is desired to take a radiographic exposure.

Furthermore by reason of the employment of a special circuit discharge of the condenser immediately follows operation of the switching means with such infinitesimal time lapse as to be substantially instantaneous and both the energy supplied to the X-ray tube by the condenser and the time period of energization of the tube can be accurately controlled within certain limits.

The aforementioned switching means comprises a thermionic discharge tube having a control electrode interposed between the anode and cathode thereof. The anode and cathode are connected to the high potential circuit in series with the X-ray tube and high capacity condenser and are consequently subjected to the same high potential heavy currents as the X-ray tube. The control electrode on the other hand is supplied with a potential from a relatively low tension auxiliary source and by maintaining this potential sufficiently negative relative to the cathode of the discharge device, and the potential between the anode and cathode I can absolutely prevent the supply of energy through the device, and consequently from the condenser to the X-ray tube.

When it is desired to take a radiographic exposure I reverse the potential of this low tension source from negative to positive without opening this low tension source, which results in an instantaneous supply of energy or discharge of the condenser upon consummation of the reversal of the polarity of the potential supplied to the control electrode. I find further that the potential of this low tension source when changed from negative to positive assists the flow of energy through the discharge device and X-ray tube to the extent of augmenting the energy supplied by the high capacity condenser. This particular phenomenon I attribute to the emission of secondary electrons from the control electrode due to the high potential heavy current energy which flows between the anode and cathode when a positive potential is impressed upon the control electrode.

It is essential for satisfactory operation that the negative potential impressed upon the control electrode be considerably higher with respect to the cathode than when supplied with a positive potential as hereinafter more fully explained.

It should also be here stated that the polarity of the potential impressed upon the control electrode must for successful operation be completely reversed without opening this source of energy. If this is not done, but instead the potential merely made less negative or reduced to zero before being made positive by interruption of the potential impressed upon the control electrode, the high potential heavy current energy will in an infinitely short period of time build up a negative potential on the control electrode resulting in again "blocking" the flow in the same manner

as when a negative potential is impressed on the control electrode from the source of energy.

Heretofore, the smallest time period in which a radiographic exposure could be successfully taken in a practical manner has been 1/120 of a second or during one half the wave of an alternating current cycle of 60 cycles per second. With an X-ray system constructed in accordance with my invention I am able to take exposures of infinitely short duration and as short, I believe, as 1/1000 of a second. This results in X-ray pictures which disclose all portions of the human anatomy regardless of the fact that the same may be in motion, such as the heart and lungs. Furthermore, due to the heavy currents and high potential the various small veins of the human body are clearly shown on the radiograph.

It is accordingly an object of my invention to provide a system for taking short exposure X-ray photographs in which the energy supplied by a high potential source to the X-ray tube may be accurately controlled with respect to time and quantum.

Another object of my invention is the provision of a switching means in the high tension circuit of an X-ray system which normally prevents the supply of energy from a high tension source to the X-ray tube and which may be rendered operative to cause substantially instantaneous flow of energy and to augment the same.

Another object of my invention is the provision of an X-ray system for taking short exposure X-ray photographs employing a thermionic discharge device in series with the X-ray tube and source of energization which is provided with a control electrode having a potential impressed thereupon normally preventing the supply of energy through the discharge device and consequently the X-ray tube and which is adapted to assist the supply of energy when impressed with a potential of opposite polarity.

A further object of my invention is the provision of a system for taking short exposure X-ray photographs in which the energy for supplying the X-ray tube is taken from a condenser and in which the supply of energy therefrom is controlled with minute precision with an entire absence of time lag.

Still further objects of my invention will become apparent to those skilled in the art by reference to the accompanying drawing in which the single figure is a diagrammatical representation of a system for taking short exposure X-ray photographs showing one form which my invention may take.

Referring now to the drawing in detail I have shown a source of commercial alternating potential, such as a generator 5. An auto transformer 6 is connected to this source by means of a pair of conductors 7 and 8. This auto transformer in turn is arranged to supply energy to the primary winding 9 of a high tension transformer 10, by means of a pair of conductors 12 and 13, when a hand operated switch 14 is closed to complete the conductivity of the conductor 13. The conductor 12 may connect to an adjustable arm of the auto-transformer, if desired, in order to vary the voltage supplied to the high tension transformer 10.

The secondary winding 15 of the high tension transformer 10 is connected to the cathode of a rectifying valve tube 16, by means of a conductor 17, and to the anode end of a similar valve tube 18, by means of a conductor 19.

The anode of the valve tube 16 is connected,

by means of a conductor 20, to a condenser 22 and the cathode of the rectifying valve 18 is similarly connected, by means of a conductor 23, to a condenser device 24. These condensers 22 and 24 are in turn interconnected by means of a conductor 25, which is suitably grounded at 26. A conductor 27 interconnects these two condensers with the mid-point of the secondary winding 15 of the high tension transformer 10. This limits the insulation requirements of the high potential system to one-half the total output energy of this secondary winding 15. The portion of my system thus far described is adapted to store relatively heavy currents at high potential in the condenser devices 22 and 24.

Although I have shown two condensers 22 and 24, respectively, and two rectifying valves 16 and 18 it can be appreciated that one condenser and one valve tube would just as readily suffice. However, should a single condenser be utilized in place of the two condensers as shown the capacity of the same would necessarily have to equal that of the two. Furthermore, in the appended claims it is to be understood that the same are to be interpreted as including the use of a single condenser and valve tube as well as the preferable form hereinabove described.

An X-ray tube 28 has its cathode end connected to the conductor 20 and condenser 22, by means of a conductor 29, and the anode end of a three electrode electron discharge device 30 is similarly connected to the conductor 23 and condenser 24, by means of a conductor 32.

The cathode of the discharge tube 30 and anode of X-ray tube 28 are connected together by means of a conductor 33. The thermionic cathode of the X-ray tube 28 is arranged to receive low tension heating currents from a heating transformer 34, the primary of which is connected to the conductors 7 and 8 extending from the source of supply 5, by means of a pair of conductors 35 and 36.

A variable resistance 37 is connected in series with one of these conductors, 36 for instance, for the purpose of regulating the cathode heating temperature of the X-ray tube. The thermionic cathodes of the rectifying valves 16 and 18 and electron discharge device 30 are likewise arranged to receive heating currents from a source of low tension supply, such as batteries or low tension transformers 38, which likewise may have their primary windings connected to the source of supply 5 in the same manner as that of the transformer 34.

The discharge device 30 in addition to its anode and cathode is provided with a control electrode in the form of a grid interposed between the anode and cathode. This control electrode is adapted to have a suitable potential from an auxiliary source impressed thereupon which is normally of sufficient magnitude to prevent the supply of the energy stored in the condensers 22 and 24 between the anode and cathode thereof, and consequently through the X-ray tube 28. This auxiliary source of potential comprises a circuit similar to that of the high voltage circuit, namely a transformer 42, having its primary winding 43 connected by means of a pair of conductors 44 and 45 to the conductors 7 and 8 extending from the source 5.

A secondary winding 46 has one of its ends connected to the anode of the rectifying valve 47 and the cathode end of a similar rectifying valve 48 by means of a conductor 49. The cathode end of the rectifying valve 47 is connected, by means

of a conductor 50, to a condenser 52 with the anode end of the rectifying valve 48 connected, by means of a conductor 53, to a condenser 54 and the opposite end of the secondary winding 46 is connected to a conductor 55, which interconnects the condensers 52 and 54.

The cathodes of the respective rectifying valves 47 and 48 are adapted to receive heating currents from a suitable source of energy 56 in the same manner as previously described relative to the sources 38. This portion of the auxiliary source of potential is arranged to store energy during each half wave of the alternating current cycle in the respective condensers 52 and 54 which are arranged to discharge through an output circuit which comprises a pair of conductors 57 and 58 connected to a plurality of resistance elements 59, 60 and 62. These respective resistance elements are connected in the form of a Wheatstone bridge circuit with the conductor 58 connected to one end of the respective resistance elements 60 and 62 and the conductor 57 connected to one end of the resistance element 59. A conductor 63 connects one end of the resistance element 62 to the control element of the discharge device 30 and a similar conductor 64 connects one end of the respective resistance elements 59 and 60 to the conductor 33 and consequently to the cathode of discharge device 30.

A pair of contact terminals 65 are interposed between one end of the resistance elements 59 and 62 which terminals are normally open but which are adapted to be bridged by means of a relay 66. This relay receives energization from a small insulating transformer 67, the primary of which is connected by means of a pair of conductors 68 and 69 extending to the conductors 7 and 8 constituting the commercial source of supply. The conductor 68, however, is provided with a pair of contact terminals disposed adjacent the aforementioned hand switch 14 and are thus adapted to be bridged by the same, as hereinafter more fully set forth.

The resistance elements 59, 60 and 62 constituting the Wheatstone bridge circuit each have equal ohmic resistance although it is not essential in every instance that their resistance be of equal ohmic value. These resistance elements are connected to the control electrode in such a manner as to constitute a polarity reverser as hereinafter more fully explained. At the operating potential of the X-ray tube, in the actual embodiment of the apparatus which I have constructed, I have found that the total output energy of the condensers 52 and 54 should be approximately 8000 volts in order to completely "block" or prevent discharge of the high voltage condensers 22 and 24. When the system is in the position as shown in the figure a negative potential of one-half the output of the low potential system is impressed upon the grid of the discharge device 30, or -4000 volts, which is of a sufficient magnitude to prevent the flow of the energy from the condenser devices 22 and 24 through the discharge device 30 and X-ray tube 28.

Although I have found that this negative potential as above noted is sufficient to "block" the flow in the high potential circuit with the potential and heavy current stored in the high potential condensers being of the magnitude employed in the embodiment I have constructed, it is to be understood that for higher or lower current and potential values the "biasing" or grid potential must be higher or lower with the ratio therebetween substantially the same.

The control electrode of the discharge device 30 now being operative to prevent the discharge of the high potential energy through the X-ray tube is then rendered operative to permit the substantially instantaneous flow and assist the same by closure of the relay 66. This establishes a different circuit by which the polarity of the potential impressed upon the control electrode of the discharge device 30 is reversed although this potential is of a slightly less magnitude due to an unbalanced condition of the resistance elements constituting the Wheatstone bridge circuit.

The operation of my system may be best understood from a given mode of operation. Assuming, therefore, it is desired to take a short exposure X-ray photograph, the cathode heating temperature of the X-ray tube 28 is set, by means of the variable resistance 37, to the desired electron emissivity. The hand switch 14 is then moved to the left completing the conductivity of the conductor 13 and energy will therefore flow from the auto transformer 6 to the primary winding 9 of the high tension transformer 10. The voltage supplied to the primary winding 9 is regulated by means of the adjustable arm of the auto-transformer to which the conductor 12 is connected to the desired potential. The secondary winding 15 causes energy to flow through the respective valve tubes 16 and 18 to the condensers 22 and 24 during alternate half waves of the alternating current cycle.

This circuit may be traced from the secondary winding 15 by means of the conductor 17 through the rectifying valve 16, conductor 20 to the condenser 22 and thence back to the secondary winding by means of the conductors 25 and 27. In a similar manner current will flow by means of the conductors 27 and 25 to the condenser 24 and thence back to the secondary winding by means of the conductor 23, rectifying valve 18 and conductor 19.

Although strictly speaking the current does not flow through the condensers 22 and 24 it can be appreciated that energy will be stored in each of the respective condensers during alternate half waves of the alternating current cycle in the manner as just described, until the same are completely charged with heavy current at a high potential to a predetermined maximum value depending upon the setting of the auto-transformer. Discharge of absolutely any of the energy stored in the condensers, however, through the output circuit comprising the discharge tube 30 and X-ray tube 28 is at this time prevented by the aforementioned action of the control electrode of the discharge tube and there is no leakage through the X-ray tube which would tend to delay the condensers in being charged to their predetermined maximum value or the generation of any X-rays of even a weak intensity. The condensers 52 and 54 will accordingly impress a sufficient negative potential upon this control electrode through a circuit which may be traced from the condenser 54, which is negatively charged, by means of conductor 58 to one end of each of the respective resistance elements 60 and 62, where the circuit divides, a portion thereof extending through the resistance element 62 to the control electrode of the discharge device 30, thus impressing a negative potential equal to one-half of the total of the output circuit thereupon. The remainder of the circuit extends through the resistance elements 60 and 59 back to the condenser 52 by means of the conductor 57.

The conductor 64 connects one end of the re-

spective resistance elements 59 and 60 to the cathode end of the discharge device 30 and therefore impresses a zero potential upon the cathode which is positive relative to that of the control electrode, the latter as aforementioned now carrying a large negative potential. This becomes readily apparent when it is appreciated that the voltage drop through the series connected resistance elements 59 and 60 is equal due to their ohmic resistance being the same. The conductor 64 being connected to the midpoint between these two resistance elements therefore is at zero potential with reference to the source. The resistance element 62 on the other hand is not connected directly in the circuit and as there is no current flowing therethrough a negative static potential is impressed upon the grid.

Assuming now that everything is in readiness to take a radiographic exposure the hand switch 14 is moved to the right, as shown in the figure, thus opening the circuit to the primary winding 9 and closing the circuit from the commercial source of potential to the primary winding of the insulating transformer 67. Energization of this winding will energize the winding of the relay 66 and cause the same to establish contact with the contact terminals 65 which constitute the remaining leg of the Wheatstone bridge circuit. Closure of this relay instantaneously reverses the polarity of the potential impressed upon the control electrode of the discharge device 30 without opening the circuit or permitting any electrical phenomenon to interfere with the simultaneous discharge of the high tension heavy current energy stored in the condensers 22 and 24 through the discharge device 30 and X-ray tube 28.

Upon closure of the relay 66 positive potential will be impressed from the condenser 52 which is positively charged, through the conductor 57, contact terminals 65 and thence through conductor 63 to the control electrode of the device 30. At the same time a current will flow through the series connected resistance elements 59 and 60 in the same manner as previously described when a negative potential was applied to the control electrode. However, as the control electrode of the discharge device 30 is now positive relative to the cathode and the latter is negative a current will flow between the cathode and control electrode forming a circuit which naturally has an inherent ohmic resistance.

This circuit is equivalent to connecting an ohmic resistance in parallel with the resistance element 59 which operates to create an effect analogous to that of lessening the ohmic resistance of the latter and render the same no longer equal to the ohmic resistance of the element 60. This will therefore cause a greater voltage drop across the resistance element 60 than across the resistance element 59, resulting in a lesser value in the positive potential impressed upon the grid than when a negative potential was previously impressed thereon. The potential at the midpoint between the respective elements 59 and 60, to which the cathode of the discharge device 30 is connected is now no longer at zero relative to the source but is carrying a potential. This potential, therefore, is impressed upon the cathode but not being as high as that impressed upon the grid enables a current to flow through the filament grid circuit comprising the resistance element 59. The high voltage energy therefore instantaneously flows between the anode and cathode without any variation or gradual rise simul-

taneously with the changing of the potential impressed upon the control electrode from negative to positive so that the energy initially supplied to the X-ray tube by the condensers 22 and 24 is at its predetermined maximum value.

The capacity of the condensers 52 and 54 are such that a constant potential of the desired polarity is always impressed upon the control electrode of the discharge device 30. The operation of my system thus far described is based on the assumption that the cathode of the X-ray tube 28 was heated to its maximum intensity which permits instantaneous flow of the energy from the high potential source upon reversal of the polarity of the control electrode. When, however, a radiographic exposure is desired of longer duration or of lesser energy output the temperature of the cathode is merely lowered by means of the adjustable resistance 37 in the cathode heating circuit and the energy stored in the condensers 22 and 24 is regulated by the auto-transformer 6.

Furthermore, it should be here noted that the switch 14, when operated to affect reversal of the potential impressed upon the control electrode of the discharge device 30, first interrupts the supply of energy to the primary winding 9 of the high tension transformer thus interrupting the charging of the high potential condensers 22 and 24 after they have been charged to their predetermined maximum value. This accordingly divorces these condensers and consequently the X-ray tube excitation circuit from the alternating current and condenser charging circuit prior to the discharge of the condensers. The result, therefore, is an entire absence of a sinusoidal ripple in the X-ray tube excitation current which applicant believes is a contributing factor of considerable import to the resulting phenomenon producing apparently X-rays of novel characteristics.

It can, therefore, be readily seen that I have provided an X-ray system for taking instantaneous X-ray photographs in which current flow in the high potential circuit is positively prevented by means of a thermionic discharge device provided with a control electrode. By impressing a negative potential upon this electrode of sufficient magnitude the high tension heavy current is completely "blocked" and upon reversal of this potential from negative to positive instantaneous energization of the X-ray tube simultaneously occurs without variation in energy supplied thereto and consequently a uniform intensity of X-rays emanating from the X-ray tube results.

Furthermore, the circuit which in one instance impresses a negative potential upon the control electrode and in the other instance impresses a positive potential thereupon is not opened during the reversal of this potential.

In consequence of this no electrical phenomenon can occur which is detrimental to the successful instantaneous energization of the X-ray tube. The latter does not become energized nor is any energy supplied during the switching operation and not until the complete consummation of reversal of the polarity impressed upon the control electrode.

Although I have shown and described one specific embodiment of my invention I do not desire to be limited thereto as various other modifications of the same may be made without departing from the spirit and scope of the appended claims.

What is claimed is:

1. In an X-ray system for taking X-ray photographs in a short interval of time, the combination with an energy storage means connected to a source of rectified alternating current energy for accumulating an electrical charge in said energy storage means, and an X-ray tube connected to said energy storage means and adapted to be energized by the charge accumulated therein, of a thermionic discharge device interposed between said energy storage means and said X-ray tube for controlling energization of the latter, an auxiliary source of electrical energy connected to one of the electrodes of said discharge device normally operative to impress a potential thereupon to prevent energization of said X-ray tube and adapted to reverse the polarity impressed upon the discharge device to cause energization of said X-ray tube by the accumulated charge, and means associated with said auxiliary source and said rectified alternating current source, and operable to reverse the polarity of the potential impressed by said auxiliary source upon one of the electrodes of said device to render said discharge device effective to cause energization of said X-ray tube by the accumulated charge and to interrupt the accumulation of a charge in said energy storage device to prevent the imposition of a sinusoidal wave form upon the X-ray tube excitation energy.

2. In an electrical system, the combination with a load, a source of high potential electrical energy therefor, and a high potential switch interposed between said load and said source provided with an anode, a cathode, and a control electrode, and operative to cause and prevent the energy from said source to be supplied to said load, of means for supplying a potential to the control electrode of said high tension switch to cause and prevent the energization of said load by said high tension source comprising a source of electrical energy connected to the control electrode of said high tension switch, a plurality of resistance elements interposed between said last mentioned source and the control electrode of said high tension switch and operative to normally cause said source to impress a negative potential upon said control electrode to render the same effective to cause said high potential switch to prevent energization of said load by said high potential source, and a switch associated with said resistance elements and operable to cause a reversal in the polarity of the potential impressed by said last mentioned source upon the control electrode of said high tension switch from negative to positive without interrupting the supply of the potential impressed upon said control electrode to cause said high tension source to energize said load upon consummation of the operation of said last mentioned switch.

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